RESTRICTED CIRCULATION

This paper is not an official document; it is for information only and reference cannot be made to it in any printed publication without the permission of the author.

AGRICULTURAL MEMORANDUM NO 523

An annotated bibliography on the effects of mulching on plant climate, with some comments on consequent yields.

Part III - Effects on soil moisture

J W DAVIES

Parts I and II of this bibliography were issued as Agricultural Memoranda Nos 392 and 423.

3.1 NO SPECIFIC CROP

Organic mulches

A 15 cm straw mulch largely prevents evaporation according to Brand (3) who also reports that the thickness of the mulch made little difference to percolation. Gardner (4), however, shows that the evaporation rate is universally proportional to the thickness of a surface mulch when the rate of vapour movement through the mulch is less than the potential evaporation. When the mulch was less than 3 mm thick, evaporation was limited by external conditions rather than by the mulch. Duley (1) meanwhile presents data to show that a mulch of plant residues greatly increases the rate of intake of water into the soil and reduces run-off and erosion.

Goode and White (5) compared the effects of clean cultivation, a permanent sward and a permanent straw mulch on soil moisture in England. The mulch of wheat straw was applied initially at 20 tonnes/ha and subsequently at 10 tonnes/ha each October. Under the mulch, soil moisture remained close to field capacity throughout the summer while under the clean cultivation evaporation losses amounted to a large part of the summer rainfall and under the sward, losses in soil moisture were 2-3 times those from the cultivated soil. However, in the relatively dry conditions of south-west Finland, Vuorinen (7) reports that mulching with straw, reduced from four to two the number of irrigations needed to prevent the soil moisture tension rising to 700 mm (Hg). Without irrigation, mulching prolonged the period of suitable moisture content in spring for about two weeks; the dry period lasted under straw for only six weeks compared with three months under an unmulched surface. Damagnez (8) suggests that a straw mulch of 5 cm thickness may become quite ineffective under climatic conditions of intense evaporation such as prevail in the Mediterranean regions.

Parr (9) reports on the effects of vertical mulching in which channels in subsoiling treatments were filled with oat straw and weeds. Samples taken 10 and 14 months later at different depths and distances showed that soil moisture was usually greater with the vertical mulch treatment. The drainage and hydraulic profiles of a soil covered with straw mulch are compared with bare soil by Hénin (13). He indicates that moisture levels were both higher and more constant under the mulch than under bare soil where there was a rapid loss of moisture especially from the top layer. Slight summer rains, or irrigation water were better utilized under the straw.

Lawes (14) discusses the effects of water conservation methods on crop production. In Nigeria the soils, which contain a high proportion of silt and fine sand, tend to cap under heavy rainfall with a consequent decrease in infiltration and increase in run-off. Surface mulches prevent capping and allow access for air and water; making a slit in the bottom of the furrow and filling it with mulching material greatly increases infiltration.

McCalla (15) summarizes developments in stubble mulching over the past 20 years and makes particular reference to the problem of the inverse correlation between crop yield and rainfall when stubble mulching is practised.

Fanning (18), and with Carter (23), shows that a mulch of cotton burr 10-12 cm thick (90 tonnes/ha) promoted the leaching of soluble salts from the top 75 cm of an infertile saline clay-loam, reducing salinity to levels innocuous to field crops. Salt concentration was decreased to a depth of 1.5 m under the mulch by flooding and sprinkling, compared with 0.6 m under bare soil where the salt accumulated below a depth of 1 m.

Mannering (19) compared the effects of various rates of straw mulching on infiltration and erosion of soil from a highly permeable silt loam of 5% slope subjected to simulated rainfall at the rate of 63.5 mm/hour for 2½ hours (159 mm). A mulch of 2.5-10 tonnes/ha maintained infiltration rates at high levels, preventing soil loss by run off: mulching at 0.5 to 1.25 tonnes/ha resulted in a soil loss of 2.5 to 7.5 tonnes/ha. The soil loss from unmulched plots was 30 tonnes/ha. Pflug (20) found that mulching with peat prevented the destruction of soil crumbs by rain and it decreased evaporation. Similarly, Nerpin (27) reports that a 1 cm mulch decreased evaporation by more than 50% and a 2 cm mulch decreased it by 70-75%.

Greb (30) reports that surface application of 1.12, 2.24 and 3.36 tonnes/ha of straw, covering 30, 60 and 90% of the surface respectively, reduced water losses from a wet soil by 16, 33 and 49% during a 20 day period. An application of 6.72 tonnes straw reduced water loss little more than 3.36 tonnes did. The effectiveness of the straw diminished with time as soil moisture was depleted.

Non-organic mulches

Collis George (17) shows that continuous or chopped bitumen mulch reduced evaporation from bare soil, but that its effectiveness decreased with increasing vegetal cover. However the better root growth and weight increase of plants grown under white and black plastic mulch found by Baumer (22) were largely attributed to increased moisture under the mulch.

Charles (24) used a 50% aqueous emulsion of petroleum resins sprayed on to the soil in pot experiments under Mediterranean conditions to form a film 0.3 mm thick. The mulch caused a reduction of 11% in evaporation when the soil moisture content was kept constant at 10%, and a reduction of 14% when loss of moisture was not compensated. However the reduction in water gained by the soil by overnight condensation varied from 13% in May to 46% in July.

Bands of petroleum mulch and polyethylene film 7.5 to 60 cm wide were evaluated by Lippert (25) for their effect on retention of soil moisture in February-March. Moisture was conserved by each material with a minimum width of 15 cm required for significance over the unmulched control. Bands of 60 cm width were superior to 15 cm bands.

Reduction in evaporation losses under a plastic mulch are shown by Pusztai (26) to result in an increase of 3-4% moisture in the 0-50 cm layer and 5-7% in the rooting zone at 10-20 cm, while Revut (28) indicates that the soil moisture content in the top 5 cm of mulched soil gradually increased as transparent polyethylene film was blackened with soot.

A porous mulch is described by Richards (29) made from commercial gravel cemented together with 10% fine sand and 10% cement mortar to hold the gravel grain in a solid array without filling the pores between. Such a mulch has beneficial effects in moisture conservation and prevents soil compaction. Surface mulches of 1, 2 or 4 cm sand were compared with 1 cm sand below 1 cm soil, by Kirkham (34) in USA. For an initially water saturated column, the mulches showed a saving of water of 46-59% for an 18 day evaporation period compared with bare soil. The surface sand mulch conserved more water than did the subsurface sand mulch, and both conserved water compared with bare soil.

Myhr (31) describes field and laboratory experiments with thin continuous asphalt films that show greatly reduced evaporation and drying especially on loose soil. The decrease in evaporation was only slightly greater under thicker films in several layers. Qashu (36) meanwhile used a black granular carbon material mulch and found that it suppressed evaporation and reduced soil crust rigidity upon drying. Hillel (40) examined the effects of light fuel oil and emulsions of latex, asphalt and wax and found that fuel oil was the most efficient for run off inducement.

Mixed mulch comparisons

Hanks (6) carried out wind-tunnel experiments on the transfer of water vapour through mulches of bare soil, gravel and straw mulch and found that evaporation rates from soil mulches were increased 2-6 times but from gravel or straw 10-15 times when the wind speed was increased from 0 to 11 m/s. The evaporation rates for gravel and straw were 1.3 times greater than for soil at 0 m/s and 6.3 times greater at 11 m/s. Increased depth of mulches decreased evaporation rates, especially in the top 0.5 cm. In a later paper (12) he found that evaporation was greater with bare soil than with mulches of straw, gravel painted black or aluminium, or plastic covers. However, the total difference in evaporation over the year between bare soil and the other treatments was no more than 2.5 cm of water. No direct relationship between net radiation and evaporation was found.

Benoit (16) found that after 600 hours unmulched cores had lost 1.25 to 5 times as much water as mulched ones in experiments under different conditions of radiation (0, 2152, 4840 lux) and air movement (0.1 and 2.3 m/s). The moisture content of both mulched and unmulched cores below a depth of 15 cm remained essentially constant with depth.

Tukey (21) reports increased moisture content and permeability of the soil when using both decomposable mulches (hay, straw, sawdust etc) and non-decomposable mulches (granular foam rubber, gravel, glass-fibre). There were no significant differences between the two types of mulches.

Experiments using plastic, fibre-glass, sand, a raised galvanised iron platform and dead natural vegetation as mulch materials on a stiff black clay 3.5 to 4 m deep are described by De Bruijn (32). With plastic and fibre-glass covers, rain infiltrated at the edges through vertical cracks in the dry soil and the expanding clay caused the cracks to close rapidly resulting in very low permeability which retarded soil drying during the subsequent arid period. This could lead to accumulation of moisture in successive seasonal cycles. A sand cover prevented soil drying and could prove a simple method of stabilising vertical movement of the soil. Grassy vegetation which had been killed by weedkiller resulted in moisture retention and a reduction in evaporation.

Jordan (33) found that only comparatively thick mulches of bitumen emulsion on smooth soil surfaces caused any appreciable reduction in water losses through evaporation, while Wiegand (39) found that a sand mulch (1.5 cm thick) and a cotton burr mulch (44.8 tonnes/ha) greatly suppressed evaporation compared with sod and bare soil when the annual average rainfall was only 58 cm.

In pot trials, Dobrenz (37) compared 6 materials and found that coarse styrofoam (particles 5-10 mm in diameter), a non-toxic, permeable, lightweight material which reduced soil moisture evaporation by 78%, was best. It allowed uniform evaporation under controlled-environment conditions with high temperatures and low humidity.

1. DULEY F L. 1953. Relationship between surface cover and water penetration, run off, and soil losses. Proc. sixth int. Grassl. Congr. 1952, 2, 942-6
2. FOGG H G W. 1954. Bark fibre as a soil improver. Grower 42, 675
3. BRAND F C. 1958. Controlling water movement in the loess loam of Dikopshof by plant cover and fallow. (in German). Z. Acker-u. PflBau 106, 257-90
4. GARDNER W R and FIREMAN M. 1958. Laboratory studies of evaporation from soil columns in the presence of a water table. Soil Sci. 85, 244-9
5. GOODE J E and WHITE G C. 1958. Soil management effects on a number of chemical and physical properties of the soil. E. Malling Res. Sta. Rep. 1956-7, 113-21
6. HANKS R J and WOODRUFF N P. 1958. Influence of wind on water vapor transfer through soil, gravel and straw mulches. Soil Sci. 86, 160-4
7. VUORINEN J. 1958. The effect of deep irrigation and straw mulching on the soil-moisture tension in heavy clay subsoil. (in Finnish). Maataloust. Aikak. 30, 36-40
8. DAMAGNEZ J. 1959. The role of natural and artificial mulch in the dynamics and economy of water in the Mediterranean region of Languedoc. (in French). C.R. Acad. Agric. Fr. 45, 237-41
9. PARR J F. 1959. Effects of vertical mulching and subsoiling on soil physical properties. Agron. J. 51, 412-4
10. WEBSTER G R and ADAMSON R M. 1960. Effects of sawdust used as a mulch and as a soil amendment on soil temperatures under irrigated and unirrigated conditions. Canad. J. Soil Sci. 40 (2), (207-11) 6 refs
11. EDMINSTER T W and STAFF C E. 1961. Plastics in soil and water conservation. Agric. Engng Mich. 42, 182-5, 248-50
12. HANKS R J, BOWERS S A and BARK L D. 1961. Influence of soil surface conditions on net radiation, soil temperature, and evaporation. Soil Sci. 91, 233-8
13. HÉNIN S and MONNIER G. 1961. Mechanism of the effect of soil cover on moisture balance. (in French). C.R. Acad. Sci. Paris 252, 939-41
14. LAWES D A. 1962. The influence of rainfall conservation on the fertility of the loess plain soils of northern Nigeria. Samaru Res. Bull. 2, 38 pp

15. McCALLA T M, ARMY T J and WHITFIELD C J. 1962. Stubble-mulch farming. J. Soil Wat. Conserv. 17, No.5, 204-8, 8 refs

16. BENOIT G R and KIRKHAM D. 1963. The effect of soil surface conditions on evaporation of soil water. Proc. Soil Sci. Soc. amer. 27, 495-8

17. COLLIS-GEORGE N, DAVEY B G, SCOTTER D R et al. 1963. Some consequences of bituminous mulches. Aust. J. agric. Res. 14, 1-11

18. FANNING C D and CARTER D L. 1963. The effectiveness of a cotton burr mulch and a ridge-furrow system in reclaiming saline soils by rainfall. Proc. Sci. Soc. amer. 27, 703-6

19. MANNERING J V and MEYER L D. 1963. The effect of various rates of surface mulch on infiltration and erosion. Proc. Soil Sci. Soc. amer. 27, 84-6

20. PFLUG J. 1963. The value of mulching in respect of some physical properties of soil. (in Czech). Sborn. vys. Škol. Zeměd. Brně 4A, 461-8

21. TUKEY R B and SCHOFF E L. 1963. Influence of different mulching materials upon the soil environment. Proc. amer. Soc. hort. Sci. 82, 68-76

22. BAUMER M. 1964. Plastic mulch, nitrogen fixation and root development. Sudan J. vet. Sci. Anim. Husb. 5, No.2, 38-9

23. CARTER D L and FANNING C D. 1964. Combining surface mulches and periodic water applications for reclaiming saline soils. Proc. Soil Sci. Soc. amer. 28, 564-7

24. CHARLES G. 1964. Effect of a petroleum mulch on evaporation and secondary supplies of humidity in soils under Mediterranean conditions. (in French). Bull. Ass. franc. Ét. Sol No.6, 250-4

25. LIPPERT L F, TAKATORI F H and WHITING F L. 1964. Soil moisture under bands of petroleum and polyethylene mulches. Proc. amer. Soc. hort. Sci. 85, 541-6

26. PUSZTAI A, ERDŐS L and PLETSER J. 1964. Recent results on mulching with plastic foils. I. (in Hungarian). Agrokém. Talajt. 13, 231-42

27. NERPIN S V and PAKSHINA S M. 1965. Residues from the distillation of alcohols as effective preparations for decreasing physical evaporation from soil. (in Russian). Dokl. vses. Akad. sel.'-khoz. Nauk No.10, 4-7

28. REVUT I B and ABROSIMOVA L N. 1965. Effect of intensity of illumina- of the soil surface on emergence of weed seedlings and biological activity of soil. (in Russian). Dokl. vses. Akad. sel.'-khoz. Nauk No.12 15-20

29. RICHARDS S J. 1965. Porous block mulch for ornamental plantings. Calif. Agric. 19, No.12, 12-4

30. GREB B W. 1966. Effect of surface applied wheat straw on soil water losses by solar distillation. Proc. Soil Sci. Soc. amer. 30, 786-8

31. MYHR E. 1966. The effect of asphalt film on evaporation, moisture content and temperature of soil. (in Norwegian). Meld. Norg. Landbrhöisk. 45, No.18, 15 pp

32. DE BRUIJN C M A. 1967. Annual vertical movements and soil moisture redistribution at the Onderstepoort test site. Proc. 4th reg. Conf. Africa, Soil Mech. Found. Engng. 235-42

33. JORDAN D and SAMPSON A J. 1967. Effect of bitumen mulching on soil conditions. J. Sci. Fd Agric. 18, 486-91, 9 refs

34. KIRKHAM D, ROLSTON D E and FRITTON D D. 1967. Gamma-radiation detection of water content in two-dimensional evaporation prevention experiments. In "Isotope and Radiation Techniques in Soil Physics and Irrigation Studies". Proc. Symp. FAO/IAEA Istanbul 3-15

35. MOORE A W. 1967. Changes in soil moisture and organic matter under different covers at Ibadan, Nigeria. Pl. Soil 27, 463-7

36. QASHU H K and EVANS D D. 1967. Effect of black granular mulch on soil temperature, water content, and crusting. Proc. Soil Sci. Soc. amer. 31, 429-35

37. DOBRENZ A K, COLE D F and JOY R J. 1968. Comparison of materials for reducing evaporation of soil moisture in water efficiency studies. Agron. J. 60, No.4, 446, 6 refs

38. SALTER P J and WILLIAMS J B. 1968. Effects of additions of farmyard manure and peat on the moisture characteristics of a sandy loam soil and on crop yields. J. hort. Sci., 43: 263-73, 17 refs

39. WIEGAND C L, HEILMAN M D and SWANSON W A. 1968. Sand and cotton bur mulches. Bermuda grass sod, and bare soil effects on: I. Evaporation suppression. Proc. Soil Sci. Soc. amer. 32, 276-80

40. HILLEL D, SCHWARTZ A, STEINHARDT R et al. 1969. Laboratory tests of sprayable materials for run off inducement on a loessial soil. Israel J. agric. Res. 19, 3-9

3.2 TEMPERATE TREE FRUITS

Organic mulches

Coutant (1) compared permanent grass and clean cultivation, with mulching with mustard grown in situ and cut in February, in an apricot orchard in Morocco where the summers are particularly hot and dry. Soil moisture in August was highest under the mulch and lowest under grass. Mulching reduced soil-moisture variations up to the end of April, and from May onwards it economised water by reducing evaporation and irrigation needs. However, a 2 year test by Gilbert (2) in Wisconsin showed that the best moisture conservation in cherry orchards was obtained by clean cultivation. Where it was advisable to grow trees in sod, however, he stressed that a heavy mulch should also be used.

Higher seasonal subsoil moisture in a grass mulch plot, indicated to Toenjes (3) in his experiments with Bartlett pears in Michigan, that a bluegrass cover conserved more water than was used for its own growth. The adverse effects of deficient summer rainfall were considerably less in the grass mulch plot than in the clean culture plot. Soil moisture studies in 1 wet and 3 dry years in apple and cherry orchards in Poland carried out by Wlodek (4) show that mulching markedly decreased the loss of soil moisture during drought period. Peat and sawdust layers 20 cm thick did not prevent rain penetration of the soil and the increase of soil moisture due to rain after dry periods was only slightly slower than in unmulched plots.

Goetz (5) compared the effects on soil moisture of a grass mulch, meadow and clean cultivated plots in an orchard in Germany. The grass mulch plots had higher moisture contents to a depth of 30 cm before the first cut which increased further before the second cut. Butijn (6) meanwhile reports on studies in an apple orchard in Holland over a period of 17 years in which the decrease in soil moisture during the summer was considerable in grass plots but only slight in straw mulch plots. Dalbro (7) however stresses one effect of using a straw mulch in apple orchards in Denmark is the protection of the surface from frequent drying and wetting.

Rasmussen (8) presents a multitude of data taken in a 4-5 year old apple orchard in Denmark and draws a conclusion that grass is wasteful of soil moisture whereas straw mulch is water-conserving, the values for water depletion in the soil at a depth of 25 cm in the middle of the summer being 80-90% under grass, 50-60% under clean cultivation and about 30% under straw. The effect of mulching with straw under bush apple trees in Germany was studied by Fuss (10). The variation of moisture values in covered soil was only half that in uncovered soil. Soil covering prevented both supersaturation of the top layer during heavy rainfall and also crust formation or drying out during drought. The effect of a mulch of 1.5 kg/sq.m. was maintained by adding 0.5 kg of straw each year to the original cover. The amount of mulching material to be used for the greatest effect was 1.5-2.5 kg/sq.m.

Ivović (11) states that hay and straw mulch improved moisture conditions in the topsoil of an apple orchard in Czechoslovakia but while Reyntens (12) also found the best moisture conservation was under straw he points out that the soil under grass required the least rain to increase its moisture content by 1% and concludes that a clover grass mixture of slow growth and low water requirement appears to be suitable for orchards in Belgium. Johansson (13) measured soil moisture contents electrically in an apple orchard experiment in Sweden over 4 years. In May and June, moisture content was similar at all depths to 40 cm in each treatment. Then the decrease in moisture content started, affecting the upper layers first. This fall was first detected under grass, then under cover crop followed by clean cultivation. Under a straw mulch, and in some years under summer cultivation, moisture scarcely fell below field capacity. In one year the moisture decrease under grass was detectable at depths of 100 cm.

Soczek (14) reports that mulching with sawdust, peat and straw all increased the levels of moisture in a Polish cherry orchard. Vuorinen (15) also shows that straw mulching preserved subsoil moisture from evaporation in a Finish orchard. Engel (17) in a German orchard experiment over 2 years, also found that the moisture content under straw mulch was higher than under a cover crop of mustard or clean cultivation. During August the moisture content was lower under the mustard than in clean cultivated soil. Van Eimern (18) states that a mulch of plant residues prevents excessive evaporation while Black (19) found an impermeable layer in the 0-15 cm zone beneath a straw mulch in a peach orchard which created a water seal resulting in the death of 25% of the trees.

Werenfels (21) found that the use of a sawdust mulch in two pear orchards in

California did not affect water penetration in comparison with clean cultivation and grass cover. However the soil under grass sward in apple orchards in Germany dried out more quickly when the grass was cut only 3 times a year and left as a mulch than when it was cut 7 times, according to Baumeister (22). This grass mulch system with frequent cutting conserved the soil water content better during dry periods than did a system of clean cultivation until June, followed by an annual cover crop.

The mulching of an orchard soil in England with strawy farmyard manure is shown by Dancer (23) to maintain the soil water content at a level higher than that under arable cultivation. The loss of moisture from the profile of the mulched soil was less than that under arable treatment, which in turn was less than that under 3 different types of cover crop. Kramer (24) however describes a clover-grass mulch strip system in use in Germany which consists of sowing a strip along the interrows (up to two-thirds of the total area) with a clover-grass mixture, while the tree rows are kept clean by chemical weed control and mulched with the clover-grass mowings. The soil moisture content was higher under the mulch than in bare soil or under the clover-grass cover (which caused considerable withdrawal of water).

Simons (28) compared mulches of straw, whole corn cobs and ground cobs and no mulch, all with and without irrigation. He found that trees on the irrigated no-mulch plots made similar growth to those on the straw mulch, non-irrigated plots.

Non-organic mulches

A mulch of black polythene sheeting used with young fruit trees in Australia is claimed by Baskett (16) to reduce the need for watering by one-third. Stephens (26) compared mulches of PVC sheeting with a 5 cm layer of wood chips and a fescue and bluegrass sward on nut tree seedlings in New England, and found that the soil moisture was greatest under the wood-chips mulch and least under the grass sward.

1. COUTANT R and PRALORAN J C. 1953. Preliminary observations on the effect of summer mulching in an apricot plantation. (in French). Fruits Prim. Afr. N. 23, 385-8

2. GILBERT F. 1955. Is it best to cultivate or mulch the cherry trees? Wis. Hort., 45: 288

3. TOENJES W. 1955. The response of Bartlett pear trees under sod mulch and clean culture systems of soil management. Mich. agric. Exp. Sta. quart. Bull. 37, 363-74, 4 refs

4. WLODEK J, WLODEK L and LENARTOWICZ W. 1955. The effect of mulching on moisture content and nutrient elements in the soil. (in Polish). Prace Inst. Sadown. Skierniewice, 1: 81-109, 31 refs

5. GOETZ J. 1956. Studies on the effect of grass mulches on the N/P/K status and plant sociological conditions. (in German). Z. Acker-u. PflBau, 102: 311-38, 90 refs

6. BUTIJN J and SCHUURMAN J J. 1957. Soil management at the experimental field at Hoofddorp. The effect of various soil management practices on soil properties and on yield and root growth of apple trees. (in Dutch). Versl. landbouwk. Onderz. 63. 16, 102 pp, 43 refs

7. DALBRO S. 1957. Soil analyses in orchards. (in Danish). Tidsskr. Planteavl, 61: 445-73, 24 refs

8. RASMUSSEN P. 1957. Water balance, meteorological and physical soil measurements in an orchard with different methods of cultivation. (in Danish). Tidsskr. Planteavl 61, 49-102, 41 refs

9. TOENJES W, MERCER J E and SAN CLEMENTE C L et al. 1957. Seasonal variation in respiration and microbial numbers under orchard mulches. Bact. Proc. 57, 10 (A6)

10. FUSS F. 1958. Changes in the soil climate resulting from mulching soil under perennial crops. (in German). Angew. Meteor., 3: 74-6

11. IVOVIĆ P and DURDEVIĆ B. 1958. The effect of mulching on chemical and physical changes in soil and on yields of apple. (in Croat). Zborn. nauč. Rad. Inst. poljopr. Istraž. Peć 1, 101-12

12. REYNTENS H and DIERIEK H. 1958. The effect of soil cover on soil moisture. (in French). Rev. Agric. Brux. 11, 818-27

13. JOHANSSON E. 1959. Soil-moisture measurements in fruit trials at Alnarp in 1954-8. (in Swedish). Medd. Trädgårdsförs. Malmö 125, 29 pp

14. SOCZEK Z. 1959. Studies on the mulching of young cherry orchards. (in Polish). Roczn. Nauk rol. 80A, No 1, 39-92

15. VUORINEN J. 1959. On soil moisture tension in a deep-irrigated orchard soil. Rep. Conf. suppl. Irrig. Comm. VI int. Soc. Soil Sci. 1958, 65-9

16. BASKETT W J. 1960. Polythene plastic sheeting for mulching fruit trees and vegetables. J. Agric. S. Aust., 64: 149

17. ENGEL G. 1960. The effect of different soil management practices on the climate of the orchard and on the growth and cropping of the fruit trees. (in German). Gartenbauwiss, 25: 67-106, 87 refs

18. VAN EIMERN J. 1961. The effect of grass cover, mulch and cultivation on soil climate in an orchard. (in German). Obstbau 8, 148

19. BLACK J D F. 1963. The development of an impermeable layer under straw mulch in a soil management trial. Aust. J. exp. Agric. Anim. Husb., 3: 101-4, 9 refs

20. BOROS R. 1963. Studies on methods of soil cultivation and organic fertilizer application to increase soil fertility in apple orchards. Preliminary communication. (in Hungarian). Kert. szöl. Föisk. Evk., 27 (11, part 1): 39-55, 26 refs

21. WERENFELS L and others. 1963. Cover crops improve infiltration rates. Calif. Agric., 17 (5): 4-5

22. BAUMEISTER J. 1964. The water supply in the soil of grass mulched orchards. (in German). ErwObstb., 6: 73-6, 8 refs

23. DANCER J. 1964. The influence of soil moisture and temperature on the growth of apple trees. I. Some observations on moisture and temperature conditions under grass, arable and mulch. Hort. Res., 4: 3-13, 13 refs

24. KRAMER S and STÖRTZER M. 1965. The clover-grass mulch strip method. (in German). Obstbau, Berlin, 5: 123-5

25. NYHLÉN A. 1965. Cultural trials with apples at Nyckelby during 1940-63. (in Swedish). LantbrHögsk. Medd., Uppsala, Ser. A, 32, 32 pp, 7 refs

26 STEPHENS G R, Jr. 1966. Initial effects of mulches on nut tree seedlings. A.R. north. Nut Grs' Ass., 62-6, 10 refs

27. STÖRTZER M. 1966. The effects of various orchard soil management practices on the availability of potassium and phosphoric acid in the soil. (in German). Arch. Gartenb., 14: 105-19, 25 refs

28. SIMONS R K. 1967. Soil management for apples - tree response to varied mulching systems. Trans. Ill. St. hort. Soc., 1966, 100: 148-53, 2 refs

29. WHITE G C and HOLLOWAY R I C. 1967. The influence of simazine or a straw mulch on the establishment of apple trees in grassed down or cultivated soil. J. hort. Sci., 42: 377-89, 9 refs

3.3 TEMPERATE HORTICULTURE AND SOFT FRUIT, VEGETABLES AND FLOWERS

Organic mulches

Strawberries

Denisen (1) found that the soil moisture was significantly higher under mulches of sawdust, chopped corncobs or straw than in unmulched plots but that the various mulches did not differ significantly in their effects. Van Adrichem (11) reports that sawdust mulching maintained a more humid microclimate around the plants and thus accentuated some disease problems. Müller (15) compared mulching with leaves with clean cultivation and also mulching with a mixture of leaves, straw and sawdust. He found that soil moisture was considerably higher in the mulched than in the unmulched beds, especially during dry periods, but there was no difference in this respect between the two types of mulch, but Wiebe (65) found that a straw mulch at 12.5 tonnes/ha reduced soil moisture slightly. Sawdust, however, when applied as a mulch and when incorporated into the soil, is shown by Webster (29) to conserve soil moisture.

Bush fruit & vines

Hansen (7) presents data on the effect of 5 cm and 10 cm sawdust mulches on soil moisture with currant crops. Fritzsche (13) found that the application of a straw mulch to raspberries reduced variations in soil moisture while Goode (69) claims that mulching raspberries with a complete surface cover of straw conserved the equivalent of 5 cm of water. Kender (58) also found that soil moisture content was higher under blueberries mulched with peat or sawdust than on unmulched plots. The effects of a straw mulch on vines was studied by Honda (49) who found that mulched plots had lower soil moisture contents from 10 July to the end of August, but higher moisture contents before and after the period.

Vegetables

Massey (9) found that sawdust mulching conserved soil moisture compared with clean cultivation in experiments with eleven vegetable crops. A similar benefit was reported by Surlekov (53) when using a straw mulch of 8 tonnes/ha applied to field grown cucumbers. Trials with irrigated potatoes by Evelyn (6) have confirmed the value of groundnut shells as a dry mulch which conserved soil moisture, and Awan (41) shows similar results with a hay mulch at rates of 5 and 10 tonnes/ha when used with potatoes in Honduras.

Rauhe (21) and Lehne (26) report an experiment using a mulch of straw or potato tops at 10 tonnes/ha, or spreading farmyard manure at 7.5 tonnes/ha on a loamy sandy soil when growing root crops in Germany. In years with a low spring rainfall, the mulched areas retained 25% more of the winter stored soil moisture than did the unmulched areas.

Flowers

Slate (2) found that 2.5 cm was sufficient depth for a sawdust mulch to conserve moisture when used with lilies. Similar results were obtained by Watson (3) who used 5 and 10 cm mulches of ground corncobs on roses, and Hoogendoorn (19) who used 1.2 to 3.8 cm mulches of shredded sugar cane stalks on cutting beds and also Čikalov (30) with straw 12-15 cm deep (5-6 tonnes/ha).

Non-organic mulches

Strawberries

Brooks (12) and Pastac (17) each show that a black polythene mulch preserved soil moisture. Similarly, Germing (18) claims that black plastic laid over initially moist soil helped to establish plants, while Thompson (23) found that an opaque plastic mulch also conserved soil moisture. Porter (33) used a black polythene mulch and found that it conserved soil moisture so well that irrigation was hardly needed, while Linden (37) shows that moisture losses by evaporation were greatly reduced by such a mulch.

In a normal year Vávra (64) found that under black, red and yellow plastic mulches the soil moisture content was higher than in the clean cultivated controls, but in a very wet year during certain periods, the soil moisture content was lower under the mulches.

Vegetables

Mareček (27) used transparent polythene film 0.08 mm thick and found that the soil moisture content under the film was 2.2 to 3.5% higher than the control throughout the season. Vlček (28) also used a transparent polythene mulch in a glasshouse, but found that moisture conditions were improved only in the top 2-8 cm soil layer.

Michurin (31) studied the water consumption of early cabbage in the Leningrad region, and shows that loss of water by transpiration represented 30% of the total evaporation in the first half of the vegetative period, and 60-70% in the second half when irrigation maintained the soil moisture content between field capacity and capillary disruption. Mulching with a transparent film decreased evaporation from the soil and increased yield more than a single irrigation did.

Milner (38) shows that the use of an inexpensive emulsion of petroleum resins, sprayed in bands 7.5 to 25 cm or more in width along the crop rows after sowing, remained intact for up to 10 weeks and greatly reduced evaporation. Lippert (45), however, compared the effects of mulches of petroleum emulsion, clear and black polythene each applied in widths ranging from 7.5 cm to 60 cm and each band being 3 metres long. In general, he found that a minimum width of 15 cm was required if soil moisture conservation was to be better than in unmulched plots and also that 60 cm width gave better results than 15 cm width.

Takatori (39) compared a petroleum mulch with both clear and black plastic and noted that the rate of moisture loss was more rapid under the petroleum mulch. Austin (40) used .04 mm black polythene film and obtained some conservation of soil moisture. Larpes (51) in a trial with Encap - a petroleum derived mulch, found slightly reduced water loss from the soil and Johnson (56) also found a reduction of 1.5% in the water loss from the top 7.5 cm of soil when using a black petroleum-base wax emulsion mulch applied in strips. Jordan (57), however, found the conservation of soil moisture using a bitumen mulch was inconsiderable compared with the total crop requirement.

Sale (61) attributes the increase in soil moisture caused by a band-sprayed petroleum mulch as one of the main effects on the emergence and establishment of vegetable seedlings, as did Wolfenbarger (71) using white and black plastics, and aluminium on paper mulches on tomatoes and squash.

Flowers

Ono (16) found that vinyl mulching on summer chrysanthemums increased soil moisture, and Elia (44) reports that mulching gladiolus corms with perforated black plastic sheeting substantially reduced irrigation requirements.

Mixed mulch comparisons

Chipman (25) compared the effects of a 5 cm sawdust mulch with a 1 m wide strip of black polythene mulch and found the moisture levels were greatest under the sawdust mulch. Schales (47 & 62) records that soil moisture in the top 15 cm was higher under mulches of peat moss and straw than under clear or black plastic or a sprayed petroleum mulch. Shetty (48) in a comparison of mulching with clear black and white polythene film with sawdust (with and without clear film) found that only sawdust, clear film with sawdust, and white film significantly increased soil moisture levels. Thorsrud (54) reports that soils mulched with black plastic dried out quicker than soils mulched with straw or sawdust.

Sogo (68) carried out experiments on a vineyard on a 20° slope. He found that a straw mulch reduced run-off, accelerated rainwater penetration and increased the uptake of water by the vines. A sod mulch had similar effects to straw on the rate of run-off but the moisture percentage was less than with the straw mulch. Application of polyvinyl alcohol (PVA) resulted in similar permeability to the sod mulch.

1. DENISEN E L, SHAW R H and VANCE B F. 1953. Effect of summer mulches on yields of everbearing strawberries, soil temperature and soil moisture. Iowa St. Coll. J. Sci., 28: 167-75, 2 refs

2. SLATE G L. 1954. Mulching lilies. RHS Lily Year Book. No 18, 72-5

3. WATSON D P. 1954. Study effects of mulching. Amer. Nurserym., 100 (11): 36-7

4. WIDMOYER F B and SHERWOOD C H. 1954. Effects of soil mulches on greenhouse roses. Proc. amer. Soc. hort. Sci. 63, 462-4 3 refs

5. EMMERT E M. 1956. Polyethylene mulch looks good for early vegetables. Market Grs J., 85(5): 18-9

6. EVELYN S H. 1956. The Swaziland Irrigation Scheme. 2. Groundnut-shell-mulching of fallow land. World Crops 8, No.2, 68-71, 2 refs

7. HANSEN E. 1956. Sawdust mulching of horticultural crops. (in Norwegian). Årsskr. PlSkoledr. Dendrol., 47-54

8. HEADY H F. 1956. Changes in a California annual plant community induced by manipulation of natural mulch. Ecology 37, 798-812

9. MASSEY P H, Jr. and JUDKINS W P. 1957. Sawdust mulch for vegetable crops. Res. Rep. Va agric. Exp. Sta. 1953-7, 224-5

10. WEBSTER G R and others. 1957. Sawdust for horticultural crops. (Mimeo.) Publ. Domin. exp. Fm, Saanichton, BC 165, 20 pp

11. VAN ADRICHEM M C J and BOSHER J E. 1958. Leaf blotch and petiole blight of strawberry caused by Gnomonia fructicola. Plant Dis. Reptr. 42: 772-5, 5 refs

12. BROOKS A N. 1958. Strawberry Investigations Laboratory. A.R. Fla agric. Exp. Stats, 1957-8, 394-6

13. FRITZSCHE R. 1958. Contribution to the aetiology of raspberry cane die-back. (in German). Arch. Gartenb., 6: 171-216, 41 refs

14. KIRSCH P K. 1959. Effects of sawdust mulches. 1. Soil properties. Oreg. agric. Exp. Sta. tech. Bull. 49, 16 pp

15. MÜLLER H and FUSS F. 1959. Mulching strawberry beds with special reference to the effect on soil moisture and temperature. (in German). Arch. Gartenb., 7: 269-84, 7 refs

16. ONO H and TAKANASHI Y. 1959. Experiments on the vinyl mulching of vegetables and flowers. (in Japanese). Bull. Kanagawa agric. Exp. Sta. hort. Branch, No.7, 57-62

17. PASTAC J P. 1959. New methods in agriculture: the use of plastic materials. (in French). C.R. Acad. Agric. Fr. 45, 176-8

18. GERMING G H. 1960. Black plastic as a soil cover for strawberries. (in Dutch). Meded. Dir. Tuinb., 23: 750-4, 6 refs

19. HOOGENDOORN C. 1960. Use of mulches in the nursery. Proc 10th annu. Mtg Plant Prop. Soc. 111-4

20. McGUIRE D C. 1960. Tomato root growth and plant placement. Hawaii Fm Sci., 9(1): 6-7, 1 ref

21. RAUHE K and LEHNE I. 1960. Yield increases in agricultural crop plants by mulching with organic matter. (in German). Albr.-Thaer-Arch. 4, No.5, 346-68, 25 refs

22. SHADBOLT C A and McCOY O D. 1960. Temperature and plant responses to paper and plastic protectors on cantaloupes. Hilgardia 30, 247-66

23. THOMPSON B D. 1960. Response of strawberries to mulching with plastic. Proc. Fla St. hort. Soc., 1959, 72: 179-85, 13 refs

24. CANNELL G H, VOTH V, BRINGHURST R S et al. 1961. The influence of irrigation levels and application methods, polyethylene mulch, and nitrogen fertilization on strawberry production in southern California. Proc. amer. Soc. hort. Sci. 78, 281-91, 8 refs

25. CHIPMAN E W. 1961. Studies of tomato response to mulching on ridged and flat rows. Canad. J. Plant Sci. 41: 10-5, 12 refs

26. LEHNE I. 1961. Mulching of arable soil with organic material. (in German). Dtsch Landw, 12, 525-9

27. MAREČEK F and TREFNÁ E. 1961. Mulching vegetables with polythene film. (in Czech). Rostlinná Výroba, 7: 663-78, 23 refs

28. VLČEK F and HOVADÍK A. 1961. The use of plastic mulches in forcing vegetables. 1. The use of plastics for mulching unheated soil in a hangar type glasshouse. (in Czech). Bull. ČSAZV výz. Ust. zelin., Olomouc, 5, 53-72, 16 refs

29. WEBSTER G R. 1961. The effect of sawdust, straw, compost and manure on the yield and chemical composition of strawberries and on soil moisture, acidity and organic matter content. Canad. J. Plant Sci., 41: 42-9, 19 refs

30. ČIKALOV P M. 1962. The effect of mulching on the development of the essential oil-bearing rose. (in Russian). Vestn. sel'sk. Nauki, 7(11): 127-31, 5 refs

31. MICHURIN B N and STEPANOVA V M. 1962. Water consumption by early cabbage and means of controlling it. (in Russian). Sborn. Trud. agron. Fiz. No.10, 125-36

32. MURATOVA E V and LEBEDEVA E A. 1962. Raising onion sets with paper mulch to protect the seedlings. (in Russian). Dokl. mosk. sel'.-hoz. Akad. K.A. Timirjazeva, No.77, 331-5

33. PORTER L A. 1962. Polythene sheet as mulch for strawberries. N.Z.J. Agric., 105: 247-55, 9 refs

34. SONDERN J A. 1962. The application of plastic films for soil mulching. Proc. 16th int. hort. Congr., Brussels, 1962, Vol.1, 139

35. FAVILLI R and BENVENUTI A. 1963. A new system of mulching with petroleum derivatives. (in Italian). Progr. agric. Bologna, 9: 1041-60

36. KROLL U. 1963. The effect of fertilizers, manures, irrigation and ridging on the yield of pyrethrum. E. afr. agric. For. J. 28, 139-45

37. LINDEN R. 1963. Soil protection with plastic mulches. (in French). Ann. Gembl. 69, 601-8

38. MILNER H B. 1963. Petroleum mulch. Nature, 197: 241-2

39. TAKATORI F H, LIPPERT L F and WHITING F L. 1963. Petroleum mulch aids germination and stand establishment in preliminary vegetable crop studies. Calif. Agric. 17(6): 2-3

40. AUSTIN R B. 1964. Plastic mulches for outdoor tomato crops and a trial of varieties. Exp. Hort. No.11, 17-22

41. AWAN A B. 1964. Influence of mulch on soil moisture, soil temperature and yield of potatoes. Am. Potato J. 41, No.10, 337-9, 4 refs

42. CHIUSOLI A. 1964. Soil moisture content and strawberry yields. The effects of mulching and irrigation. (in Italian). Ital. agric. 101: 752-6, 9 refs

43. DHESI N S, NANDPURI K S and SINGH A. 1964. Effect of mulching and irrigation on the soil temperature for potato culture. Indian J. Agron. 9, 277-80

44. ELIA P and ACCATI E. 1964. The use of black polythene sheeting for mulching gladioli: effects on soil moisture and on the crop. (in Italian). Frutticoltura, 26: 249-56, 12 refs

45. LIPPERT L F, TAKATORI F H and WHITING F L. 1964. Soil moisture under bands of petroleum and polyethylene mulches. Proc. Amer. Soc. hort. Sci. 85: 541-6, 10 refs

46. MUTHUSWAMY S and THAMBURAJ S. 1964. A note on the effect of mulching with black polythene film on the vegetative vigour of grape var. Anab-e-Shahi. S. Indian Hort., 12: 95-8, 2 refs

47. SCHALES F D. 1964. A study of some physical and biological effects of various mulching materials when used with several vegetable crops. Diss. Abstr. 24, 3487

48. SHETTY B S. 1964. Effects of polyethylene film mulches and sawdust on the vegetative and reproductive behaviour of Red Rich strawberry plants. Diss. Abstr. 25, 4340-1

49. HONDA N and others. 1965. Studies on the premature defoliation of Campbell Early grape vine. II & III. The effect of soil management (1 & 2). (in Japanese). Sci. Rep. Fac. Agric. Okayama. No.26, 19-25, 10 refs: 27-34, 12 refs

50. KASAHARA Y and NISHI K. 1965. Effect of mulching with plastic films on intensity of illumination, temperature, moisture and pH of soil, growth of lettuce and weed control. (in English). Ber. Ôhara Inst. landw. Biol. 12, 287-303, 15 refs

51. LARPES G. 1965. Field trials with Encap, a petroleum derived mulch. (in English). Maatalous ja Koetoim., 1965, Vol 19, p 5

52. RAHMAN F. 1965. Effect of mulches, levels of nitrogen and soil moisture conditions on growth and yield of cauliflower. Indian Agriculturist, 9: 59-71, 31 refs

53. SURLEKOV P. 1965. Straw mulching late cucumbers. (in Bulgarian). Grad. lozar. Nauka, 2: 339-44, 7 refs

54. THORSRUD J. 1965. Cultural trials with strawberries. VI. Trials with black plastic as a mulch. (in Norwegian). Yrkesfruktdyrking, No.1. 1-6, 2 refs

55. - 1966. Plastic covering and irrigation of early potatoes. (in Danish). Medd. 790 St. ForsVirk. PlKult. No.26, 4 pp

56. JOHNSON W H, HEDDEN O K and WILSON J D. 1966. How liquid mulches affect moisture retention, temperature and seedling growth. Agric. Engng, St. Joseph, Mich. 47, 196-9, 211, 9 refs

57. JORDAN D and SAMPSON A J. 1966. Crop responses to bitumen mulches. Span, 9: 157-60, 4 refs

58. KENDER W J and EGGERT F P. 1966. Several soil management practices influencing the growth and rhizome development of the lowbush blueberry. Canad. J. Plant Sci. 46: 141-9, 9 refs

59. MIYASAKA S and others. 1966. The effects of mulching with different forms of non-decomposed organic matter and of incorporating these in the soil immediately before planting, on bean crops. (in Portuguese). Bragantia, 25: 349-63, 9 refs

60. OVERCASH J P. 1966. Mulches for strawberries. Miss. Fm Res., 29(7): 1-2

61. SALE P J M. 1966. Effect of petroleum mulch on seedling emergence, soil moisture and soil temperature. Expl Hort. No.14, 43-52

62. SCHALES F D and SHELDRAKE R, Jr. 1966. Mulch effects on soil conditions and muskmelon response. Proc. Amer. Soc. hort. Sci., 88: 425-30, 19 refs

63. VAN NERUM K, PALÁSTHY A and LAMBERTS D. 1966. A study of soil requirements for strawberry growing. (in Flemish). Agricultura, Louvain, 14: 491-530, 7 refs

64. VÁVRA M and KLÍČNÍKOVÁ V. 1966. The effect of mulching with plastic film on the soil moisture content and strawberry yields. (in Czech). Śborn. vys. Śk. zeměd. v Brně, Řada A, No.4, 551-63, 3 refs

65. WIEBE J and others. 1966. Effects of additions of straw on soil temperature and moisture, and on yield of potatoes, strawberries and beans. Rep. Ont. hort. Exp. Stats Prod. Lab. 1965, 40-7, 9 refs

66. BRANZANTI E C and CELOTTI C. 1967. The effects of different coloured plastic films on the microclimate of plots on which they are used as mulch. (in Italian). Inf. agrar., Verona, 23: 2085-6, 1 ref

67. CARUSO P. 1967. Experiences in the use of plastic materials in market gardening in Sicily. (in Italian). Atti II^{o} Congr. int. Appl. Mat. plast. Agric. Pisa, 1966, 83-94, 19 refs

68. SOGO M and OZAKI M. 1967. Soil management of the slope land orchard. 2. Effect of soil management on fertilizer losses, physical and chemical characteristics of the soil and yield of grapes. (in Japanese). Bull. Shikoku agric. Exp. Stn 16, 35-68

69. GOODE J E and HYRYCZ K J. 1968. The response of Malling Jewel and Malling Exploit raspberries to different soil moisture conditions and straw mulching. J. hort. Sci. 43: 215-30, 8 refs

70. THORSRUD J. 1968. Variety and mulching trial with blackcurrants grown in hedgerows. (in Norwegian), Forsk. Fors. Landbr. 19. 477-86

71. WOLFENBARGER D O and MOORE W D. 1968. Mulch treatments of squash and tomatoes with respect to virus infections and yields. Proc. Fla St. hort. Soc. 1967, 80: 217-21, 5 refs

3.4 FORESTRY

Organic mulches

Bakkay (2) recommends the use of a loose straw mulch on about 30-40% of the area to protect the soil against raindrop-impact, together with overhead irrigation to maintain constant soil moisture in a Poplar seedbed, while Leyton (3) attributes the beneficial influence of a heather mulch on cypress trees primarily to the better moisture conditions, particularly during dry periods when the superficial roots of the trees are otherwise liable to desiccation. However, Woods (7), found that a 5 cm mulch of longleaf pine needles for 45 cm radius around selected seedlings, did not increase soil moisture and he does not recommend it for sandy sites.

Dakev (8) used chopped straw mulches 2, 4, 6, 8 and 10 cm deep in a nursery and kept records of soil moisture under them to depths of 40 cm during the summer. He found that 2 cm mulches were best in a wet year but in a normal or dry year he recommends a 4 cm mulch.

Van Nierop (9) compared mulches of (1) sphagnum peat, (2) reed-sedge peat, (3) a hardwood/softwood sawdust mixture and (4) softwood chips. He found a significant increase in the water stability of the soil with (3) and the greater thickness of application and the better physical stability of both (3) and (4) gave superior moisture retention. On the basis of results and costs (3) and (4) are preferred to (1) and (2).

Simon (10) improved moisture retention in the soil by mulching with shavings and chips from the making of fence posts. Koshi (17) also found that moisture levels were generally higher under a pine needle mulch except after a prolonged drought, despite slightly higher moisture depletion rates during much of the time. Higher moisture levels under the mulch resulted almost entirely from superior accretion due probably to higher surface infiltration rates. With mulching, moisture depletion rates were controlled more by transpiration than by evaporation.

Non-organic mulches

Blanke (11) describes the results of a 2 year experiment using black polyethylene foil, 0.08 mm thick and 20 cm wide used between rows of Spruce transplants which conserved soil moisture.

Meiman (18) gives details of a greenhouse study which involved combinations of 0-20% (by volume) and 0-62% surface cover of sandstone fragments in or on a clay loam soil. The greatest measured reduction of water loss from 25 cm of soil associated with a 62% surface cover was 4 mm for a 54 day drying cycle while 22-44% cover had no effects at all. Available water was not increased by the coarse fragments in the soil. Mustafaev (21) improved the moisture regime of a moderately eroded skeletal soil on a southern slope by using a 2-layered mulch of flat stones placed around seedlings.

Mulching with 60 x 60 cm sheets of asphalt interlined paper of light grey colour is described by Hermann (19). When applied immediately after planting or in early spring before much moisture was lost by plant uptake and evaporation it was beneficial in keeping the soil moist for some time. The mulch started to disintegrate with the onset of autumn rains. DeByle (26) meanwhile obtained beneficial results by mulching with 90 x 90 cm sheets of black plastic with 15 cm slits in the middle for Pine seedlings, probably owing to prevention of evaporation from the soil in hot dry weather.

"Plastsoil", a synthetic foam, was used by Sturm (25) in preliminary experiments which demonstrated its usefulness as an insulating material to reduce transpiration in transplanted trees.

Mixed mulch comparisons

Lebedenko (1) shows that a 2-3 cm mulch of "gumbrin" - a clayey waste product of the oil industry - proved more effective than manure in conserving moisture.

1. LEBEDENKO L A. 1952. Cultivation of Quercus ilex on the Apsheron peninsula. (in Russian). Lesn. Hoz. 5 (7), 19-20

2. BAKKAY L. 1954. The raising of Poplar seedlings. (in Hungarian). Erdő 3 (8), 267-70

3. LEYTON L. 1955. The influence of heather mulching on the growth and nutrient status of Lawson cypress. Forestry 28, 147-51, 6 refs

4. BOGGESS W R et al. 1956. Sawdust mulch aids tree survival. For. Note Ill. agric. Exp. Sta. No.69, 7 pp, 3 refs

5. KNEŽEVIĆ I. 1956. Some remarks on the raising of Platanus growing stock. (in Croat). Šum. List 80 (1/2), 28-30

6. VON PECHMANN H and RONDE G. 1956. Experiments in mulching to counteract the desiccating effects of wind on open forest margins. (in German). 12th Congr. int. Union For. Res. Organ., Oxford 1956 No. 1UFRO/56/11/3, 3 pp

7. WOODS F W, HEBB E A and FASSNACHT D L. 1956. Mulch not beneficial to seedlings on deep sands. J. For. 54(9), 595

8. DAKEV T and NAUMOV Z. 1958. Investigation to find the most suitable mulch in 'Cerovski Livadi' forest nursery. (in Bulgarian). Gorsko Stopanstvo 14(7), 16-21

9. VAN NIEROP E T and WHITE D P. 1958. Evaluation of several organic mulching materials on a sandy loam forest nursery soil. J. For. 56, 23-7, 10 refs

10. SIMON K.-H. 1959. Mulching of pine plantations with chips. (in German). Abstr of thesis, in Forst u. Jagd 9(8), 376-7

11. BLANKE, H K. 1960. Experience with plastic films (for mulching) in a forest nursery. (in German). Allg. Forstzeitschr 15(30), 424-6

12. LOWRY G L. 1960. Conifer establishment on coal spoils as influenced by certain site factors and organic additions at planting time. Proc. Soil Sci. Soc. Amer. 24 (4), 316-8, 6 refs

13. WATT R F. 1960. A test of wood fibre pads as a seedbed mulch. Tree Plant. Notes No.41, 5 7

14. STRANSKY J J. 1961. Weed control, soil moisture and Loblolly Pine seedling behaviour. J. For. 59 (4), 282-4, 289-90

15. WAISEL Y et al. 1961. Effect of sand mulch on sprouting and establishment of Tamarix aphylla cuttings and Eucalyptus gomphocephala seedlings. Bull. Res. Coun. Israel 9D (4), 149-54, 3 refs

16. GABRIEL W J. 1962. Experience with black polyethylene film for mulching hardwood transplants. Tree Plant, Notes No.51, 25-8

17. KOSHI P T and STEPHENSON G K. 1962. Shade and mulch as influences on Loblolly Pine seedlings and their immediate environment. For. Sci. 8 (2), 191-204, 16 refs

18. MEIMAN J R. 1962. Influence of coarse fragments on soil moisture and soil temperature. Diss. Abstr. 23, 2646

19. HERMANN R K. 1964. Paper mulch for reforestation in southwestern Oregon. J. For. 62, 98-101

20. HOFFMAN H L. 1964. A comparison of petroleum, sand, and Pine straw mulches on Eucalyptus seedbeds. Tree Plant. Notes No.66, 12-4

21. MUSTAFAEV KH M. 1964. A stone mulch for tree crops. (in Russian). Vestn. s.-kh. Nauki No.10, 88-92

22. STEPHENS G R, Jr. 1965. Accelerating early height growth of White Spruce. J. For. 63 (9), 671-3, 5 refs

23. STEPHENS G R, Jr. 1965. Yellow Poplar seedlings respond to soil temperature. J. For. 63 (9), 701-3, 3 refs

24. KELLER T. 1966. Trials to control winter discoloration on needles of shoot tips of Spruce in nurseries. (in German). Schweiz. Z. Forstw. 117 (10), 706-19, 18 refs

25. STURM M. 1967. Plastsoil, a new synthetic foam in horticulture. (in German). Dtsche Gärtnerbörse, 67: 593-6, 9 refs

26. DeBYLE N V. 1969. Black polyethylene mulch increases survival and growth of a Jeffrey Pine plantation. Tree Plant. Notes 19 (4), 7-11, 13 refs

3.5 GRASSES AND CEREALS

Organic mulches

Hopkins (2) made observations on the effect of different amounts of mulch ranging from 1 to 25 tonnes per hectare. On mulched sites, infiltration over a 2-hour period was 183% greater than on unmulched sites. The mulch appeared to be very effective for decreasing evaporation losses from a soil which was moist at the surface, but had little effect on moisture losses after the soil surface had dried. Evaporation losses were not in direct proportion to the depth of the mulch. Mulched plots at the end of the growing season had available moisture present to a depth of 120 cm compared with 60 cm on unmulched plots.

Borst (5) used mulches of straw (5 tonnes/ha) and manure (25 tonnes/ha) and found that run-off on 10° and 12° slopes was reduced by an average of 6 cm. Goetz (7) used a grass mulch (up to 15 cm) and found that the moisture content to depths of 30-40 cm was higher in mulched plots than under grass, and that down to 10 cm it was higher under the mulch than in bare soil. White (12) associated increased moisture availability with the higher crop yields obtained on plots mulched with 2.5 to 3.7 cm of sawdust mulch (50 tonnes/ha). Moody (21) also found that a mulch of wheat straw at 7.5 tonnes/ha had a favourable effect on soil moisture. Samiy (24) however reports that a straw mulch of 3.6 tonnes/ha had unfavourable effects on the structure of heavy soil of high moisture content in rainy years but beneficial effects on that of light soil in dry weather conditions.

Mannering (33) applied a surface mulch of 7.5 tonnes of dry hay per hectare after the first cultivation on sloping ground used for maize, and found that soil and water loss was eliminated during the rest of the crop season.

Stubble mulching

Duley (1) discusses the effect of stubble mulch farming on controlling wind erosion and conserving soil moisture while Burnham (4) says that in areas where precipitation averages 380-460 mm, a stubble mulch is essential to reduce wind damage and the drying of surface soil. Harris (19) shows that soil moisture storage was increased in 3 years out of 6 under stubble mulching, and it was not decreased in the other 3 years.

Non-organic mulches

Shaw (11) reports that maize grown in soil covered by black plastic sheeting intercepted 3.3-4.8 mm of water during rains of more than 7.6 mm. The loss of soil moisture was 46% of that from uncovered plots. When intercepted water as well as soil moisture loss was calculated as total water loss, then the covered plots were 90% of the uncovered plots when solar radiation was 250 cal/sq.cm/day and only 72% when solar radiation was 550 cal/sq.cm./day.

Army (13) compared the effects of aluminium or white paint sprayed over the soil, with sheets of polyethylene, roofing paper or aluminium foil spread over it. All coverings kept the moisture content at about 20% in the 0-6 mm zone compared with 2% for bare soil. White, clear and black plastic foil mulches 0.08 to 0.1 mm thick are shown by Pusztai (22) to have increased the soil moisture in the 0-50 cm layer by an average 2.8% irrespective of the colour of the foil.

A 3-year study on the use of translucent plastic sheeting is reported by Free (26). When the plastic was installed over the row just after emergence and was allowed to fit tightly around the base of each plant without being slit between the rows (to exclude rain), yield increases were obtained from a withdrawal of only 97 mm of moisture from the top metre of the soil; in the absence of the plastic or when it was slit, soil moisture losses were 3 times this amount. Griffin (32) also claims greater water economy using a total or partial soil cover of plastic film, or a partial cover of asphalt or asphalt-coated paper.

Mixed mulch comparisons

Straw, gravel or dioctadecyl dimethylammonium chloride (DDAC) treated soil were applied as mulches to 0.004 ha plots on a 4% slope by Adams (30). Run-off was greater from the DDAC treated soil than from bare soil, but run-off was significantly reduced by the straw and the gravel mulches. All treatments reduced the rate of evaporation of soil moisture, the most effective being the DDAC treated soil and a 5 cm gravel mulch. During high rainfall, straw and gravel mulches increased infiltration and movement of excess water.

The effectiveness of 8 mulching procedures was investigated by Beard (31). Moisture conditions were limiting during the initial months of the experiment. Straw alone, straw plus asphalt and "Mulch-net" over straw mulches at seeding time were significantly superior to various manufactured mulches which also lacked the property of adequate soil moisture retention.

1. DULEY F L. 1954. Stubble-mulch wheat farming methods for fallow areas. Neb. Coll. Agric. and USDA EC 54-100, 16 pp

2. HOPKINS H H. 1954. Effects of mulch upon certain factors of the grassland environment. J. Range Mgmt 7, No.6, 255-8, 11 refs

3. KELLER E R. 1954. The effect of various nurse crops on the development and yield of fodder crops with particular reference to microclimatic factors. (in German). Promotionsarb. 2356, Eidg. Techn. Hochsch, Zürich, 133 pp, 90 refs

4. BURNHAM D R. 1955. Reseeding abandoned cropland or depleted range areas in eastern New Mexico. N. Mex. agric. Exp. Sta. Bull. 395, 13 pp

5. BORST H L and MEDERSKI H J. 1957. Surface mulches and mulch tillage for corn production. Ohio agric. Exp. Sta. Res. Bull. 796, 19 pp

6. GEIZSLER G N. 1957. Crop yields are affected by tillage practices. Bi-mon. Bull. N. Dak. agric. Exp. Sta. 19, No.6, 3-8, 7 refs

7. GOETZ J. 1957. Investigation of the effects of grass mulch on the NPK economy and plant-sociological conditions. (in German). Z. Acker u. PflBau 102, 311-38, 90 refs

8. PARKER D T, LARSON W E and BARTHOLOMEW W V. 1957. Studies on nitrogen tie-up as influenced by location of plant residues in soils. Soil Sci. Soc. Amer. Proc. 21, 608-12

9. - 1959. Grass cover established under difficult conditions. Aqua, Vict. 10, No.8

10. MOLDENHAUER W C. 1959. Establishment of grasses on sandy soil of the southern High Plains of Texas using a mulch and simulated moisture levels. Agron. J. 51, No.1, 39-41, 4 refs

11. SHAW R H. 1959. Water use from plastic-covered and uncovered corn plots. Agron. J. 51, No.3, 172-3, 3 refs

12. WHITE A W, Jr., GIDDENS J E and MORRIS H D. 1959. The effect of sawdust on crop growth and physical and biological properties of Cecil soil. Soil Sci. Soc. Amer. Proc. 23, 365-8

13. ARMY T J and HUDSPETH E B. 1960. Alteration of the microclimate of the seed zone. Agron. J. 52, 17-22

14. BURROWS W C. 1960. Mulch influence on soil temperature and corn growth. Diss. Abstr. 20, 3451-2

15. FENSTER C R. 1960. Stubble mulch controls run-off. Nebraska Exp. Sta. Quart. 6, No.4, 3-4

16. - 1962. Esso agricultural mulch. Revised edn, 142 pp, 10 refs

17. PARKER D T and LARSON W E. 1962. Crop residue replacement in soil and its effect upon growth of corn. Agron. J. 54, 263-7

18. RATTRAY A G H. 1962. Stubble mulching and trash farming. Rep. Sec. Fed. Min. Agri. Rhod. and Nyasald 1961, 77

19. HARRIS W W. 1963. Effects of (crop) residue management, rotations, and nitrogen fertilizer on small grain production in northwestern Kansas. Agron. J. 55, No.3, 281-4, 12 refs

20. KOJNOV G. 1963. Wheat development and yield as affected by cotton stems left after harvest. (in Bulgarian). Nauč. Trudove, visš. selskostop. Inst. "Vasil Kolarov", Plovdiv, Bulgaria (Agron. Fak.), 12, No.1, 289-98, 4 refs

21. MOODY J E, JONES J N and LILLARD J H. 1963. Influence of straw mulch on soil moisture, soil temperature and the growth of corn. Proc. Soil Sci. Soc. Amer. 27, No.6, 700-3, 10 refs

22. PUSZTAI A. 1963. The effect of plastic mulch on the soil and plant. (in Hungarian). Agrokém. Talajt. 12, 351-60

23. READ D W L and ASHFORD R. 1964. Further study on the effect of a white surface mulch on growth of sweet clover in the greenhouse. Can. J. Pl. Sci. 44, No.4, 384-5, 2 refs

24. SAMIY H. 1964. The effects of undersowing, mulching and weedkillers on maize production. (in German). Bayer. landw. Jb. 41, 798-813

25. TAYLOR R E, HAYS O E, BAY C E et al. 1964. Corn stover mulch for control of run-off and erosion on land planted to corn after corn. Proc. Soil Sci. Soc. Amer. 28, 123-5

26. FREE G R and BAY C. 1965. Effects of plastic mulch on the growth, maturity, and yields of corn. Proc. Soil Sci. Soc.Amer.29, No.4, 461-4, 9 refs

27. HARRIS R E. 1965. Polyethylene covers and mulches for corn and bean production in northern regions. Proc. Amer. Soc. hort. Sci. 87: 288-94,12 refs

28. MORENO M V. 1965. Three methods for sowing subterranean clover. (in Spanish). Boln Inst. nac. Invest. agron. Madr. 25, No.52, 241-53, 11 refs

29. SIMMONS P and ARMSTRONG W J. 1965. A new method of soil (and sand) stabilisation. (in English). Z. PflErnähr. Düng. Bodenk. 110, No.3, 215-25

30. ADAMS J E. 1966. Influence of mulches on run-off, erosion, and soil moisture depletion. Proc. Soil Sci. Soc.Amer.30, 110-4

31. BEARD J B. 1966. A comparison of mulches for erosion control and grass establishment on light soil. Quart. Bull. Mich. agric. Exp. Stat., 48: 369-76, 11 refs

32. GRIFFIN R H, OTT B J and STONE J F. 1966. Effect of water management and surface applied barriers on yield and moisture utilization of grain sorghum in the southern Great Plains. Agron. J. 58, No.4, 449-52, 17 refs

33. MANNERING J V, MEYER L D and JOHNSON C B. 1966. Infiltration and erosion as affected by minimum tillage for corn (Zea mays L.). Proc. Soil Sci. Soc. Amer.30, No.1, 101-5, 13 refs

34. GERAKIS P A and TSANGARAKIS C Z. 1968. Rehabilitation of the pediplain ("gardud") soils of the central Sudan. Agron. J. 60, No.4, 396-400, 4 refs

3.6 TROPICAL AND SUB-TROPICAL CROPS

Organic mulches

Soil moisture measurements showed Pereira (3) that an important additional conservation of water could be achieved by applying grass mulches before the rains (in Kenya) to improve reception, rather than by the customary applications after the rains, to prevent evaporation. Warden (28) confirms this result but Lee (41) recommends the end of the rainy season as a suitable time for mulching. Earlier mulching may induce poor drainage on heavy clay soil but not on loams. Sand mulch is good only on heavy clay soil.

Smith (4) found that mulching had little effect on soil moisture between the surface and 15 cm depth, but in the 15-30 cm layer, soil moisture tended to be lower under the mulch. Taylor (7) also reports reduced fluctuations in soil moisture under a mulch of wood shaving while Medcalf (8) used a grass mulch to obtain an increase in available soil moisture as did Bolton (9) with a trash mulch. Mulches of straw and bunch stalks were used by Wormer (13) who reports that soil moisture was more plentiful in the top 15 cm of soil under the unwatered mulch, particularly under the straw, than in regularly watered bare soil. Su (15) and Onchev (19) each found increased soil moisture contents using straw mulches, as did Pisani (20) who used a straw mulch 8-10 cm thick.

Stolzy (22) obtained greatly improved water intake rates using wood shaving mulches on a sandy loam soil but Cahoon (23) reports from similar experiments that there were no substantial differences between the rates of moisture depletion in mulched or bare soil. Lawes (25) meanwhile carried out experiments with cotton in an area where natural rainfall is not a limiting factor, and showed that the efficiency of infiltration varied from 30% for bare soil to more than 90% for various mulches. Chang (29) however found that mulching was better at planting than at the beginning of the dry season. Mulching decidedly increased moisture storage when little effective rainfall occurred in the dry winter months following planting in Taiwan but had little or no effect on moisture storage in a very dry winter.

A note of caution is introduced by Black (35) who investigated the death of peach trees following mulching with straw. He found that the occurrence of a relatively high moisture content in the 0-15 cm depth showed that there was an impermeable layer under the mulch. High surface run-off and low porosity supported this view and he concludes that the trees probably died from surface waterlogging.

The effects of a banana trash mulch and of irrigation on the root development of coffee was studied by Bull (37) in an experiment which lasted 20 years. Growth of primary and secondary lateral roots and the depth of penetration of the tap root was increased by the mulch. The results suggest that a plantation, irrigated but not mulched in its early years, may be made more vulnerable to drought in later years if irrigation is discontinued; cessation of mulching should be less damaging.

Fanning (39) found that a mulch of cotton burr, 10-12 cm thick (90 tonnes/ha) increased the efficiency of rainwater in reducing salinity in the top 75 cm of a soil, to a level below that limiting crop production. The mulch reduced evaporation from the soil and hence the upward movement of salts. Mathur (47) shows that the application of a trash mulch, 15-30 cm thick, after harvesting sugar cane resulted in better soil moisture conservation and Panje (48) obtained a 4-12% increase in soil moisture, also with a trash mulch.

Rajamanickam (51) used a trash mulch to reduce by half the frequency of irrigations needed to obtain optimum yields of sugar cane and Thompson (52) similarly found yield increases due to moisture conservation through reduced run-off and transpiration with a trash mulch. The trash intercepted some rain but the losses were easily offset by its moisture conserving effects. Mulches of parchment, banana leaves, elephant or Guatemala grass were all found by Alférez (53) to increase the moisture content of the topsoil in the dry season.

Archibald (54) took weekly moisture readings at depths of 15 and 30 cm in a peach orchard under mulch, sod or bare soil for 2 years. Half the plots were irrigated when the moisture fell below 50% of field capacity at 15 cm depth. Mulching had a beneficial effect on moisture except when a prolonged dry period was followed by frequent light showers.

Growing tobacoo under a straw mulch, with and without surface incorporated straw, is shown by Batchelder (55) to increase water infiltration, conserve soil moisture and, by favouring root development, to reduce lodging. Ninane (63) reports that the use of a grass mulch resulted in a daily saving in evapotranspiration of 12-14 cu.m/ha and considerably decreased the rate of water loss. In Russia, mulching tea with peat at 50 tonnes/ha (3-4 cm deep) increased the moisture content in the 0-15 cm soil layer by 1.7%, while at 100 tonnes/ha the moisture content rose by 4.4% according to Iosava (69). Results given by Shyu (70) also show that a rice straw mulch at the rate of 20 tonnes/ha increased the moisture content of the soil.

Non-organic mulches

Lu (5) reports that mulches of 7.5 cm thick mixture of coarse sand and gravel increased soil moisture on a field scale and decreased salt concentration.

Coit (10) conserved soil moisture by using 1.5 m square sheets of black polythene mulch with a slit for the trunk, for newly planted avocado trees. Similar claims are made by Smith (17) on tobacco fields, also using a black polythene mulch and Devočkin (38) using antiseptic, bitumen-treated cellulosic paper bands 15 cm wide with 2 cm holes for the cotton seed and by Hopkinson (68) also with a black polythene mulch. Panje (44) meanwhile compared the effects of black and translucent polythene mulches and found that more moisture was conserved under the translucent cover.

A black plastic soil cover was used by Hongler (46) who found that the soil beneath remained moist even after 3 weeks without rain, whereas uncovered soil dried out to a depth of 10 cm. Bennett (56) also reports a reduced rate of soil moisture loss using a black plastic mulch but Ekern (61) says that moisture use, measured by semi-contained hydraulic lysimeters was reduced by a black plastic mulch only when the soil was very wet but was little changed as the soil dried out from field capacity. Castello (65) however reports reduced requirement for irrigation water using plastic sheets with tobacco.

Phillips (49) used a petroleum mulch applied at 6750 litres/ha in 20 cm strips over cotton rows but found that it had no effect on soil moisture 0-5 cm beneath the strip. Results quoted by Gerard (62) however suggest that the use of 4000-6000 litres/ha of reflective coating materials will adequately suppress evaporation.

Mixed mulch comparisons

Gogolishvili (1) reports that mulching with tarred paper, bracken or peat increased soil moisture by 2-10%, while results quoted by Gvazava (11) show that soil moisture was highest under two mulch treatments, viz: a mulch of organic material throughout the year and a black paper mulch until August followed by annual grasses. Randhawa (21) however compared mulching with black alkathene and dried leaves. Black alkathene with weekly irrigations conserved soil moisture most effectively but a dry leaf mulch was also fairly effective and much cheaper.

Engle (30) reports experiments with straw, paper and polythene mulches. In no case was mulching considered to be economic, though the soil moisture was higher in both normal and dry seasons. Py (50) meanwhile shows that black polythene was significantly superior to straw as a soil covering for limiting water loss in the dry season. After $2\frac{1}{2}$ months the moisture content under polythene was equivalent to that of the bare soil 2 months previously, whereas the straw and bare soil treatments approached wilting point. However polythene could not prevent wilting point being reached by the end of the dry season.

1. GOGOLISHVILI M A. 1954. The effect of mulching on the yield of citrus in the Adzharian ASSR. (in Russian). Soobshch, Akad. Nauk Gruzin, SSR 15, 359-62.

2. HAVORD G. 1954. Mulching for cacao. V Reun. Com. tec. interamer. Cacao 1, Doc. 5, 12 pp

3. PEREIRA H C and JONES P A. 1954. Field responses by Kenya coffee to fertilizers, manures and mulches. Emp. J. exp. Agric. 22: 23-36, 25 refs

4. SMITH G W. 1954. Some physical aspects of the cacao shade experiment. A.R. Cacao Res. I.C.T.A. 1953, 38-44, 3 refs

5. LU C S and CHEN P Y. 1955. Studies on the sand-mulch system of soil management in Kansu. (in Chinese). Acta Agric. sin. 6, 299-312

6. MEDCALF J C and others. 1955. Experimental programs in Brazil. Coffee horticulture and plant chemistry. IBEC Res. Inst., 9-30

7. TAYLOR O C and CAHOON G A. 1955. Orchard rejuvenation field studies. Calif. Citrogr. 40: 400, 424-7, 4 refs

8. MEDCALF J C. 1956. Preliminary study on mulching young coffee in Brazil. IBEC Res. Inst. No.12, 47 pp, 47 refs

9. BOLTON J. 1957. Record of investigations 1955-6. Bull. Dep. Sci. Agric., Barbados 25, 24 pp

10. COIT J E. 1957. Black polyethylene plastic for mulching newly planted trees. Yearb. Calif. Avoc. Soc. p 99

11. GVAZAVA Š T. 1957. The growth, development and fruiting of young orange trees in relation to methods of soil management in the interrows. (in Russian). Bjull. Vses. n.-i. In-ta Čaja i subtrop. Kul'tur, No.1, 116-43, 33 refs

12. LAWES D A. 1957. Preliminary report on soil-water-crop relationships at Samaru, Northern Nigeria, 1956. Emp. Cott. Gr. Rev. 34, 155-60

13. WORMER T M and OCHS R. 1957. Soil moisture and growth of oil palms in the nursery. (in French). Oléagineux 12, 81-9, 3 refs

14. KIBE M M. 1958. The role of vegetal cover in soil conservation. J. Soil Wat. Conserv. India, 6, No.4, 160-6

15. SU N R and others. 1958. Effects of rice straw mulching on pineapples. (in Chinese). Soils and Ferts, Taiwan, 1956-7, 42-3

16. HASTIE M S. 1959. Treatment of partially waterlogged land. Progr. Reps Exp. Stas Emp. Cott. Gr. Corp, Kenya 1958-9, 2-3

17. SMITH E M. 1959. Mechanizing tobacco production. Ky Fm Home Sci., 5 (3): 4-6

18. MUNRO J M. 1960. Mulching and ridging of crops. Progr. Reps Exp. Stas Cott. Gr. Corp. Nyasald Protect. 1958-9, 6

19. ONCHEV N G. 1960. The effect of mulching on the moisture content and heat regime of soil. (in Bulgarian). Khidrol. Meteorol. No.4, 43-52

20. PISANI P L. 1960. Observations on the character of peach root systems and on soil moisture content in relation to different cultural techniques. (in Italian). Riv. Ortoflorofruttic. ital., 44: 32-45, 39 refs

21. RANDHAWA G S, SINGH J P and DUDANI G. 1960. Preliminary studies on the effect of soil management systems on soil moisture in a sweet orange orchard. Indian J. Hort., 17: 246-9, 3 refs

22. STOLZY L H and SZUSZKIEWICZ T E. 1960. Water intake and soil surface conditions. Calif. Citrogr., 45: 309, 311, 2 refs

23. CAHOON G A, STOLZY L H and MORTON E S. 1961. Effects of mulching on soil-moisture depletion in citrus orchards. Soil Sci., 92: 202-6, 11 refs

24. LAWES D A. 1961. Crop physiology. Progr. Reps Exp. Stas Emp. Cott. Gr. Corp., N. Nigeria 1959-60, 7-9

25. LAWES D A. 1961. Rainfall conservation and the yield of cotton in Northern Nigeria. Emp. J. exp. Agric. 29, No.116, 307-18, 21 refs

26. NADARAJA G B. 1961. Increasing the winter hardiness of citrus crops. (in Russian). Vestn. sel'sk. Nauki, 6(1): 51-3

27. VAN AMSON F W. 1961. A soil improvement trial on low-lying sand in the citrus nursery at Dirkshoop. (in Dutch). Surinaam. Landb., 9: 81-92

28. WARDEN J C. 1961. The action and value of organic mulches on the yield and nutrition of the coffee tree. Coff. Res. Sta. Lyamungu Res. Rep. 1960, 25-33

29. CHANG H, WO I W and HSU L. 1962. Effects of mulching on a non-irrigated lateritic soil in Taiwan. (in Chinese). Rep. Taiwan Sugar Exp. Stat., 28, 39-73, 17 refs

30. ENGLE H B and others. 1962. Mulches for Maryland and Pennsylvania tobacco. Tobacco, N.Y., 154(19): 27-33, 7 refs

31. ONCHEV N. 1962. Characteristics of temperature and moisture regimes in the layer of air above ground mulched with straw. (in Bulgarian). Izv. tsentral nauch.-izsled. Inst. Pochvoznan. Agrotekh. "Pushkarov" 5, 125-35, 6 refs

32. PREVOT P and BILLAZ R. 1962. Agro-physiological investigations on the problem of the resistance of the groundnut to drought. (in French). Oléagineux, 17, No.12, 911-7, 13 refs

33. WALLIS J A N. 1962. Irrigating arabica coffee in Kenya. Africa and Irrigation. 221-35, 20 refs

34. - 1963. The use of plastic on tobacco. (in French). Voix Plant. Tabacs, No.204, p 7

35. BLACK J D F. 1963. The development of an impermeable layer under straw mulch in a soil management trial. Aust. J. exp. Agric. Anim. Husb. 3, 101-4

36. BULL R A. 1963. Effects of mulching and irrigation on some East African coffee soils. A review. Turrialba 13, 22-7

37. BULL R A. 1963. Studies on the effect of mulch and irrigation on root and stem development in Coffea arabica L. 1. Changes in the root system induced by mulching and irrigation. Turrialba 13, 96-115

38. DEVOČKIN F A, DIANOV V I and EDEL'ŠTEĬN V I. 1963. Sowing cotton with bands of paper to protect emerging plants. (in Russian). Izv. Timirjazevsk. S-H. Akad. No.1, (50), 7-11, 6 refs

39. FANNING C D and CARTER D L. 1963. The effectiveness of a cotton bur mulch and a ridge-furrow system in reclaiming saline soils by rainfall. Proc. Soil Sci. Soc. Amer. 27 No.6, 703-6, 6 refs

40. JAZYKOV P P and MUHAMEDŽANOV R Z. 1963. Experiments on sowing cotton under mulch-paper. (in Russian). Hlopkovodstvo (Cott. Prod.) 13, No.6, 44-7

41. LEE L H, LEE T T, LEE K M et al. 1963. Mulching on plant-cane fields. (in Chinese). Rep. Taiwan Sug. Exp. Sta. 32, 41-66

42. NAKAHARA M and HADA W. 1963. Results of observations on the soil moisture and temperature conditions prevailing in a sloping orange orchard. (I). (in Japanese). Tech. Bull. Fac. Hort. Chiba. No.11, 37-43, 3 refs

43. PEREIRA H C. 1963. Studies on the effect of mulch and irrigation on root and stem development in Coffea arabica L. 2. A five year water-budget of a coffee irrigation experiment. Turrialba, 13: 227-30, 12 refs

44. PANJE R R, GILL P S and ALAM M. 1964. Studies on conservation of moisture for sugarcane crop. II. Use of polyethylene film as soil cover. Indian Sugarcane J., 9: 6-8

45. ROBINSON J B D and MITCHELL H W. 1964. Studies on the effect of mulch and irrigation on root and stem development in Coffea arabica L. 3. The effects of mulch and irrigation on yield. Turrialba, 14: 24-8, 8 refs

46. HONGLER M. 1965. The system of covering with plastic film. (in Portuguese). Gaz. agric. Angola, 10: 285-7, 298

47. MATHUR P S and SAKSENA M M. 1965. On the utility of trash mulch in sugarcane ratoons. Indian Sugarcane J., 16: 24-7, 7 refs

48. PANJE R R. 1965. Trash mulching will trap soil moisture in sugarcane. Indian Fmg, 15(9): 13-4

49. PHILLIPS R E and FRANS R E. 1965. Effect of petroleum mulch on growth and yield of cotton in eastern Arkansas. Bull. 199 Arkans. agric. Exp. Stn, 21 pp

50. PY C. 1965. Attempts to overcome water shortage, the principal limiting factor of pineapple growing in Guinea. (in French). Fruits d'Outre Mer, 20: 315-29, 4 refs

51. RAJAMANICKAM D and EKAMBARAM C. 1965. Trash mulch in cane culture at Cuddalore. Indian Sugar, 14: 751-6, 7 refs

52. THOMPSON G D. 1965. The effects of trash conservation on soil moisture and the sugarcane crop in Natal. Proc. (39th) Congr. S. Afr. Sug. Technol. Ass., 1965, 143-56, 9 refs

53. ALFÉREZ A and ESPINOSA F M. 1966. Effect of the application to a coffee field of mulches derived from various sources. (in Spanish). Agricultura, El Salvador, 7(1/2/3): 75-87, 5 refs

54. ARCHIBALD J A, CLINE R A and REISSMANN H J. 1966. Soil moisture and temperature relationships as influenced by surface mulching. Rep. Ont. hort. Exp. Stats Prod. Lab. 1965, 23-8, 4 refs

55. BATCHELDER A R, ROGERS M J and WALKER J P. 1966. Effects of subsoil management practices on growth of flue-cured tobacco. Agron. J. 58, 345-7, 8 refs

56. BENNETT O L, ASHLEY D A and DOSS B D. 1966. Cotton responses to black plastic mulch and irrigation. Agron. J. 58, No.1, 57-60, 10 refs

57. BHATTACHARYA J, VASUDEVAIAH R D and TFOTIA S P S. 1966. Effect of different soil moisture conserving measures on the yield of Mosambi in Upper Damodar Catchment. Indian J. Hort., 23: 30-8, 5 refs

58. CHOUTEAU J, RENIER A and LOCHE J. 1966. Effect of watering and plastic mulching on certain physical and chemical characteristics of tobacco. (in French). Ann. Dir. Étud. & Équip., SEITA Sect 2, No.3, 135-44, 3 refs

59. COCKROFT B. 1966. Soil management of peach trees in the Goulburn Valley, Victoria. Aust. J. exp. Agric. Anim. Husb., 6: 62-5, 7 refs

60. THOMSON G D. 1966. Trash mulching - its effects on soils and crops in South Africa. World Crops, 18(2): 62-5, 5 refs

61. EKERN P C. 1967. Soil moisture and soil temperature changes with the use of black vapor-barrier mulch and their influence on pineapple (Ananas comosus (L.) Merr.) growth in Hawaii. Proc. Soil Sci. Soc. Am. 31, 270-5, 16 refs

62. GERARD C J and CHAMBERS G. 1967. Effect of reflective coatings on soil temperatures, soil moisture, and the establishment of fall bell peppers. Agron. J., 59: 293-6, 7 refs

63. NINANE F. 1967. The actual evapotranspiration and growth of young hevea subjected to different soil humidities. (in French). Rev. gén. Caoutch., 44: 207-12, 4 refs

64. STEFFENS G L and MILES J D. 1967. Plastic-covered plant beds for flue-cured tobacco. 2. Soil fertility and plant nutrition as affected by fertilizer rate, soil moisture level and ventilation temperature. Tobacco, N.Y., 164, No.2, 28-33

65. CASTELLO W J and ULLIVARRI D F DE. 1968. Plastic covers for tobacco seedbeds. (in Spanish). Idia, No.244, 8-14, 6 refs

66. CHOUTEAU J, LOCHE J and RENIER A et al. 1968. Effect of plastic soil cover and of irrigation on evapotranspiration of tobacco crops and on production characteristics. (in French). SEITA Annls No.5, Sect.2, 39-59

67. GARCIA V. 1968. Black polythene as a soil covering in banana cultivation. (in French). Fruits d'outre-mer 23, 480-2

68. HOPKINSON D. 1968. Experiments on mulching sisal with black polythene in Tanganyika. Expl Agric. 4, 143-50

69. IOSAVA V. 1968. Mulching the tea plantation. (in Russian). Zemledelie, Mosk., 29(1): 46

70. SHYU I S and WU C T. 1968. Effect of mulching on soil temperature and soil moisture and on the growth, yield and quality of young tea. (in Chinese). J. agric. Ass. China 61, 67-78, 3 refs

Any comments or suggestions on this paper should be sent to the author.

Meteorological Office
ADAS, Burghill Road
Westbury on Trym
Bristol
BS10 6NJ

January 1973

RW 00903/1/TP165 70 1/73 BL